Electronic Supplementary Information

Vertical Recrystallization for Highly Efficient and Stable Formamidinium based Inverted Structure Perovskite Solar Cells

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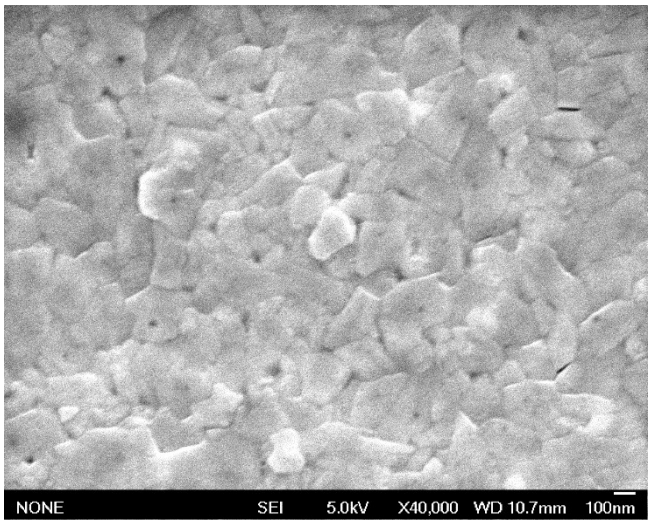

Figure S1. SEM image of $FAPbI_3$ film without annealing (δ -$FAPbI_3$ film).The crystal size is around 100 nm.

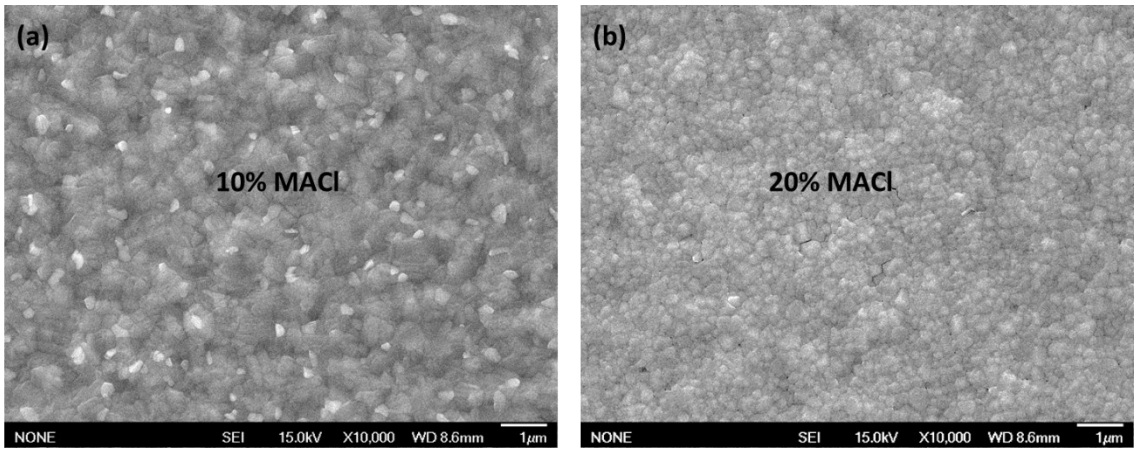

Figure S2. SEM image of perovskite film formed by mixed $FAPbI_3$+MACl in precursor solution. (a) $FAPbI_3$(MACl 10%), (b) $FAPbI_3$(MACl 20%). The perovskite films were thermal annealed at 100°C for 10 min and then annealed at 140°C for 20min.

Different from MACl vertical recrystallization method, the perovskite film formed by the mixed $FAPbI_3$+MACl method showed small perovskite grains (about 200nm), which is consistent with previous report.[1]

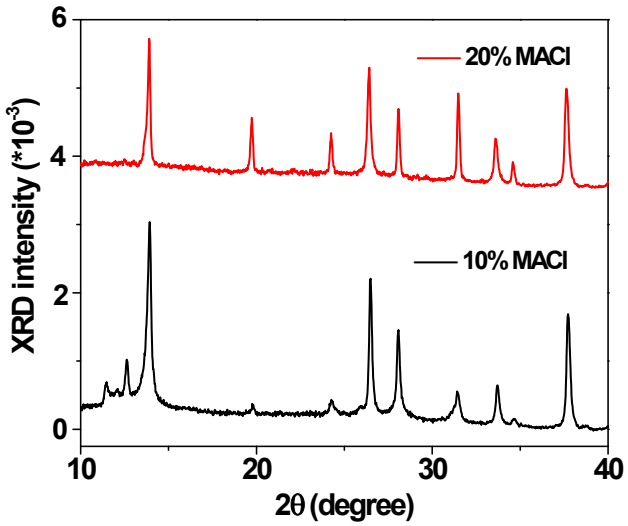

Figure S3. XRD spectrum of perovskite film formed by mixed $FAPbI_3$/MACl. (a) $FAPbI_3$(MACl 10%), (b) $FAPbI_3$(MACl 20%). The perovskite films were thermal annealed at 100°C for 10 min and then annealed at 140°C for 20min. Different from MACl vertical recrystallization method, the perovskite film formed by the mixed $FAPbI_3$+MACl method showed very weak XRD peak.

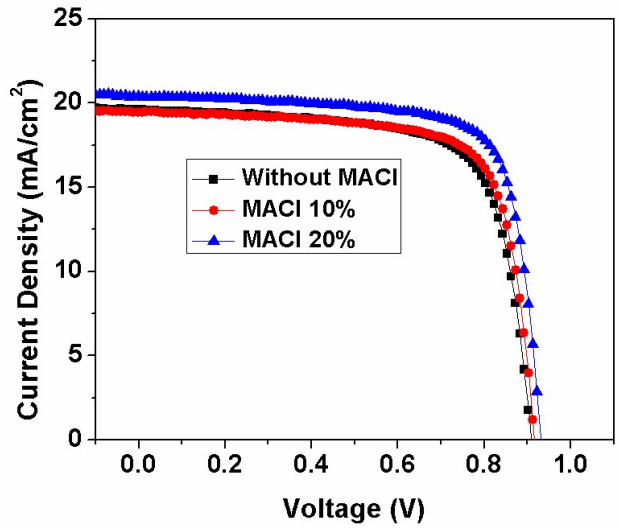

Figure S4. Current density-voltage (J-V) curves $FAPbI_3$ perovskite device using pristine-$FAPbI_3$ film (black square dots line), mixed $FAPbI_3$+MACl 10% (red rounded dots line), and mixed $FAPbI_3$+MACl 20% (blue triangle dots line). The perovskite films were thermal annealed at 100°C for 10 min and then annealed at 140°C for 20min.

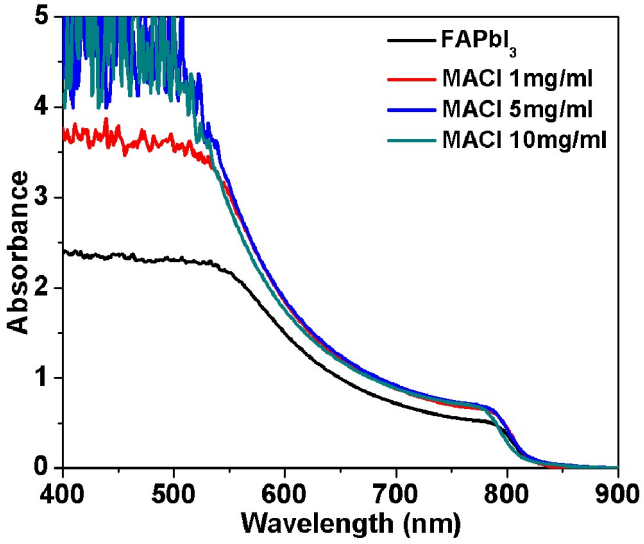

Figure S5. Absorbance spectra of $FAPbI_3$ film with different MACl concentration treatment.

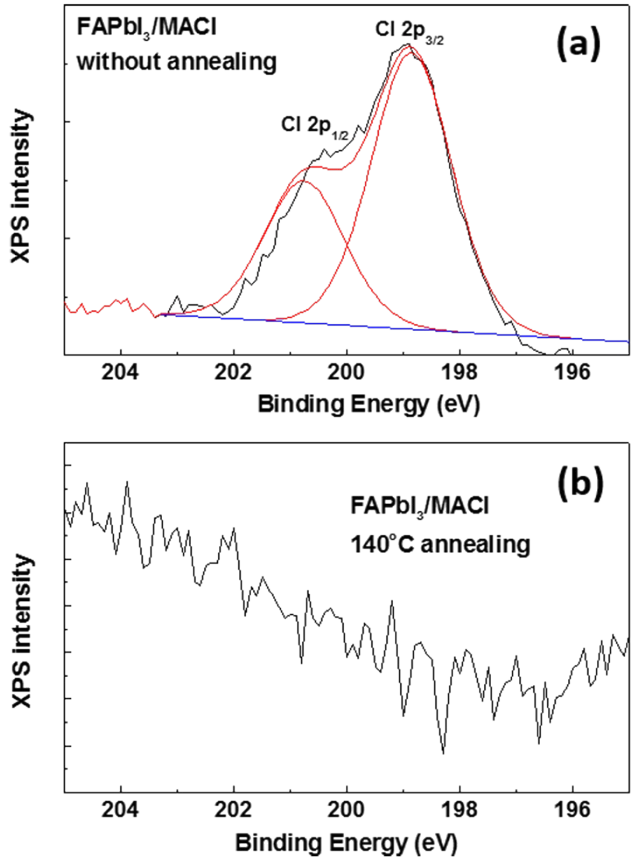

Figure S6. XPS spectrum of XPS spectra (Cl 2p core level) of (a) a $FAPbI_3$ perovskite film with 10 mg/ml MACl spin-coated on top surface without thermal annealing. (b) a $FAPbI_3$ perovskite film with 10 mg/ml MACl treatement after thermal annealing at 100°C for 10 min and 140°C for 20 min, indicated little amount of Cl was remained in the perovskite film.

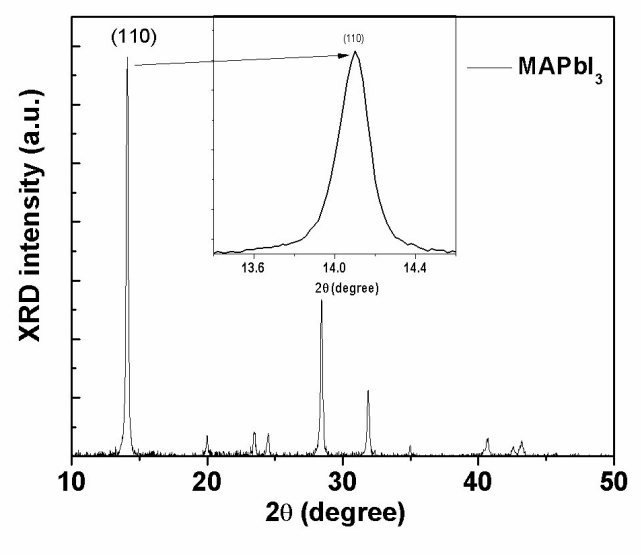

Figure S7. X-ray diffraction pattern of $MAPbI_3$ film.

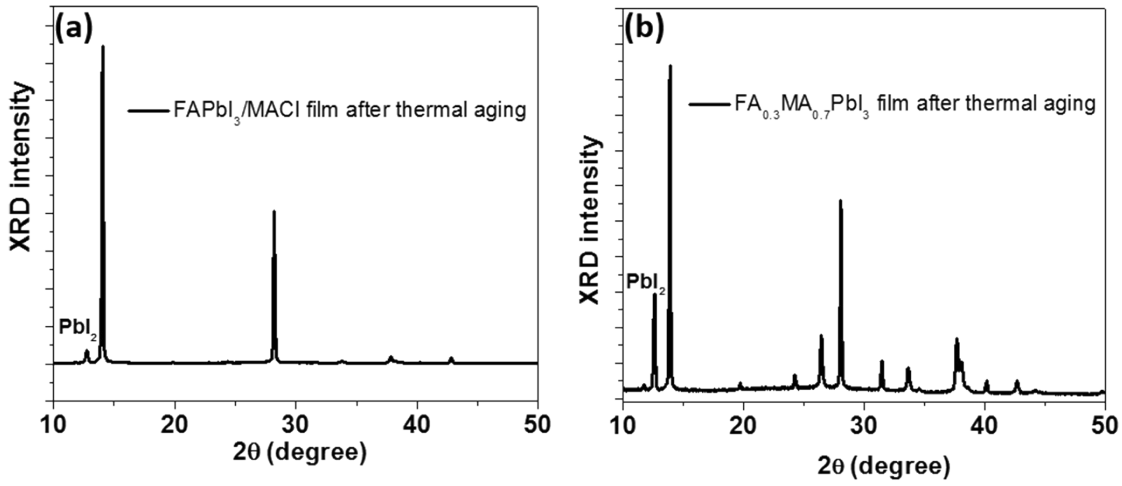

Figure S8. (a) XRD spectrum of thermal aged perovskite film (Vertical recrystallization method, $FAPbI_3$/MACl 5mg/ml). (b) XRD spectrum of thermal aged perovskite film ($FA_{0.3}MA_{0.7}PbI_3$ by reported method[2]). Thermal aging of perovskite films were performed at 100°C on hot plate for 50 hours in glove box.

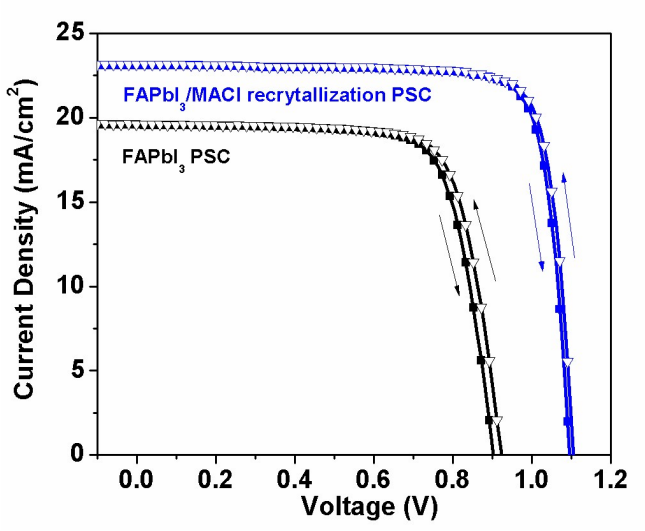

Figure S9 Hysteresis behavior of pristine $FAPbI_3$-based PSC and $FAPbI_3$/MACl (5 mg/ml) based inverted PSC.

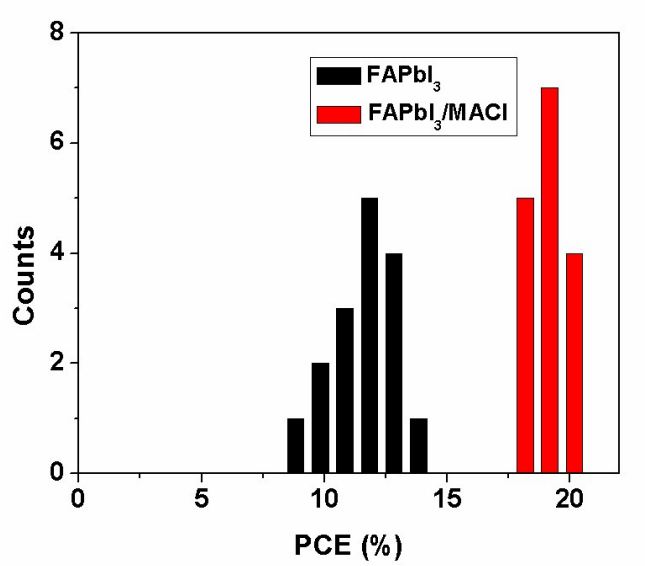

Figure S10. Statistical PCE of of the pristine $FAPbI_3$-based PSC and $FAPbI_3$/MACl (5 mg/ml) based inverted PSC.

Table S1. Photovoltaic data obtained from $FAPbI_3$ perovskite device with 0mg/ml, 1mg/ml, 5 mg/ml and 10mg/ml MACl treatment.

	V_{oc} (V)	J_{sc} (mA/cm^2)	FF	PCE %
without MACl	0.91	19.57	0.741	13.24
MACl 1mg/ml	1.02	20.49	0.751	15.72
MACl 5mg/ml	1.10	23.09	0.814	20.65
MACl 10mg/ml	1.09	22.51	0.811	19.89

Table S2. Summary of lattice parameters for perovskite films

Perovskite film	XRD (110)	lattice parameter
$FAPbI_3$	13.86	6.384
1mg/ml MACl	13.88	6.375
5mg/ml MACl	13.90	6.366
10mg/ml MACl	13.96	6.339
$MAPbI_3$	14.10	6.276

Reference:

[1] Z. Wang, Y. Zhou, S. Pang, Z. Xiao, J. Zhang, W. Chai, H. Xu, Z. Liu, N. P. Padture, G. Cui, Chemistry of Materials 2015, 27, 7149.
[2] J. Liu, Y. Shirai, X. Yang, Y. Yue, W. Chen, Y. Wu, A. Islam, L. Han, Advanced Materials 2015, 27, 4918.